ENRICHING SCHOOL SCIENCE FOR THE GIFTED LEARNER

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PREFACE

This SEP publication is designed to support science teachers, those with responsibility in science departments, and Gifted and Talented coordinators in schools. All schools are now expected to identify their most able students – the 'Gifted and Talented', and to demonstrate that the special needs of this group are being addressed, following inspection findings that indicated that, in general,

> **"very able pupils in maintained primary and secondary schools are often insufficiently challenged by the work they are set"** [1]

Those comments were made by the Inspectorate in 1992, and as recently as 2004 the Chief Inspector of Schools has reported that

> **"Consistently high-quality provision for gifted and talented pupils, for example in secondary schools, remains the exception rather than the rule."** [2]

Meeting the learning needs of the most able is now a focus of school inspections, and schools will be judged on how they ensure that their highest attaining students are facing appropriate intellectual demands. Schools, and individual departments, need advice on how best to provide for this group of students.

The present guidebook offers such advice for the science department, distilling the best current advice from the various sources available. Although there has been limited specific research in this area in the UK context, this may now be starting to change. There is certainly much useful material available from elsewhere, and especially in the US context - where provision for the gifted in science has been an ongoing concern from some time. There is also a good deal of research into aspects of science teaching and learning which, whilst not directed at the gifted in particular, has obvious links with what we know about this group of students. [3]

All schools are now required to identify their 'gifted' students, and to ensure that they are being challenged to meet their potential. This guidebook is intended to offer practical advice on how to meet the learning needs of the most able in science.
The guidebook provides an overview of some key issues in gifted science education:

- Who are the learners who may be considered gifted in science?
- What is the nature of giftedness in science education?
- How can schools and teachers plan appropriate provision to meet the needs of this group?

These are major topics, and the present slim publication is only able to offer an introduction to some of the key thinking about gifted science education. References are included to allow those interested to follow up these topics in more detail.

Part of the impetus for this publication derived from a concern among some in science education, both in universities and schools, that the needs of the most able learners were not easily addressed within science lessons constrained by the English National Curriculum (with its 'whistle-stop' tour of myriad science topics, but little time to explore issues in any depth). This led to a collaborative project between the Universities of Cambridge, Reading and Roehampton: APECS- Able Pupils Experiencing Challenging Science (http://www.educ.cam.ac.uk/apecs/). The focus of the project was a University of Cambridge Faculty of Education Seminar Series on Meeting the Needs of the Most Able in Science which demonstrated that there was quite a good deal of useful relevant thinking around, although little actual research exploring how the most able can be challenged in science. Teachers need practical advice, supported by a solid research base, and this guide is intended to offer the 'best current advice' in a currently under-researched field.

In particular, it draws upon a project supported by SEP (the Science Enhancement Programme), to design and implement a programme of after-school enrichment activities for Y10 (14-15 year olds). The ASCEND project (Able Scientists Collectively Experiencing New Demands) was a collaborative project involving the University of Cambridge Faculty of Education working with the Confederation of Secondary Schools in the City of Cambridge. Students from four of the City schools came together in the Faculty of Education to work together on a series of activities designed to complement school science provision. Funding from SEP supported the development of new teaching resources (made available with this publication) as well as the logistical support for the research/development project. The project was staffed by science graduates studying in the Education Faculty, who acted both as teaching assistants and also as research assistants recording their observations on the sessions.

Figure 1: *Students were carefully observed during ASCEND*

We also recorded some of the dialogue between students working together, to provide a record that would allow us to consider the level at which the students were working. Although space does not allow the inclusion of detailed accounts of all our observations, a few 'bites' have been included to give a feel for the way students were able to engage in and respond to the activities.

Figure 2: *'Miked-up' - digital recorders were used to capture some of the dialogue during ASCEND sessions*

The nature of science was used as the main theme for the ASCEND project. Original teaching materials prepared for these sessions are available on the accompanying CDROM. It is hoped that these activities will be useful as examples of activities that can be incorporated into school provision more widely. Although ASCEND was a collaborative venture, run as an after school enrichment programme, it may well be that schools will wish to adopt or adapt some of these teaching resources for use in other ways when working with their gifted scientists.

By providing the rationale for activities, and an indication of what the students at ASCEND made of these particular activities, it is hoped that the guidebook will provide science departments with ideas on how to develop their own materials and activities suitable for their own most able science learners.

CONTENTS:

CHAPTER 1: WHAT IS 'GIFTED'?

This brief chapter reviews what is meant by the term 'gifted' in he context of 'gifted and talented' provision in UK schools.

Secondary schools in the UK are expected to identify a cohort of gifted and talented pupils within each year group, based on a simple consideration of percentiles.'***Gifted***' is used to refer to high ability in academic subjects, and '***talented***' for high ability in creative subjects such as music, and in sports;

> **" 'Gifted' pupils have evident high attainment in academic subjects; 'talented' pupils have evident high attainment or latent high ability in a creative or expressive art or a sport."** [4]

So *in terms of these definitions*, students can be gifted in science, but are not 'talented' in science! Science does of course have a creative aspect (and one which becomes central to achievement at the highest levels), and we might feel that high levels of achievement in practical work demonstrate a talent, [5] but to fit with the officially sanctioned definition, this guidebook talks of 'gifted' rather than 'talented' learners in science.

Schools have been asked to identify those considered to have:

- ability in one of the 'academic' subjects (the 'gifted')
- talent in art, music, PE, sport or creative arts (the 'talented')
- all round ability (those both 'gifted and talented').

5-10% of each year group should be identified as Gifted and/or Talented, two thirds of which should be considered Gifted (including those considered to be both Gifted *and* Talented). Within the Secondary Strategy (formerly the KS3 National Strategy) the term '***able***' is used to include both gifted and talented pupils. The identified cohort is relative to a particular school, rather than some National or absolute measure:

> **"pupils who achieve, or who have the ability to achieve, at a level significantly in advance of the average for their year group in their school."** [6]

(The Strategy also refers to the category of the '***exceptionally able***' - defined as the most able 1% of the cohort nationally).

The policy derives from an initiative known as ‘Excellence in Cities’ (EiC) designed to tackle perceived underachievement in many urban schools, “to help disadvantaged able children, many of whom are underachieving, to reach their full potential”. [7] The main elements of the G&T strand of EiC were:

- Identifying the gifted and talented cohort;
- A whole school policy for meeting the needs of this cohort;
- A distinct in-school teaching and learning programme for the cohort
- An extensive programme of out-of-hours study support opportunities for those pupils (which could be provided through networks of schools working together).

The approach has since been extended to all schools. So in UK schools, science departments should have a list of those students who have been identified as ‘gifted’ in the context of that school and for whom special provision is being made. The official logic here is that the most able learners in any school are in danger of underachieving unless planning takes them into account as one group of students who have special needs.

Any register of ‘Gifted students’ also has a negative function: it *excludes* most students from being considered as among the gifted. It is important to remember that there is no absolute distinction between gifted and non-gifted students: the use of arbitrary quotas is not based on any sound research or theoretical considerations. [8] Teachers need to bear in mind that (as pointed out above) notions of giftedness are contentious, and it would be unwise to assume that students on a gifted register can always be expected to show suitable gifted behaviour in science lessons. Moreover, it would be even less wise to assume that students not included in such lists are never capable of demonstrating exceptional abilities, or must lack the potential to demonstrate giftedness that has previously gone unrecognised.

In this guidebook, therefore, it will be assumed that teachers will use their professional judgment about when and how to recognise and respond to giftedness in their classes. The next chapter offers advice about the indicators which science teachers may use to identify students who are best considered gifted in science.

> **‘one group member seemed to absorb information like a sponge… perfectly comfortable flipping from absorption in the materials provided, to contributing to the discussion’**
>
> *(Observation recorded by one of the graduate assistants during ASCEND)*

CHAPTER 2:
WHO ARE GIFTED IN SCIENCE?

This chapter provides a brief introduction to thinking about the nature of giftedness, particularly in science . It begins by considering how 'giftedness' is commonly understood (in terms of general characteristics, rather than simply a percentage of a cohort), and then reports some of the indicators that have been used to identify gifted learners in science.

What do we mean by gifted?

The term 'gifted' is widely used around the world, although it is one of those terms that is often used differently by different writers. Although teachers tend to know what they mean by 'the gifted', it is much more difficult to get general agreement on what the term actually means, and who it should include. [9]

Robert Sternberg, a leading expert on intelligence and related topics, suggests that judgements of giftedness should be based on a set of criteria relating to an unusual ability considered by society to be of value. According to Sternberg, a gifted person must be

- extremely good at something,
- that is rare among peers;
- that leads to a productive outcome;
- that can be clearly demonstrated;
- and which is valued. [10]

Furthermore, Sternberg discounts such excellence as giftedness, *if* it is brought about by training and practice.

Where Sternberg seems to be referring to a giftedness that 'comes naturally', Stepanek argues that, just as intelligence "is not static and can be learned, then giftedness can also be developed". [11] So Renzulli has developed a notion of giftedness, one that comprises of

- above-average ability plus
- creativity plus
- task commitment or motivation. [12]

Some descriptions of giftedness include a wide range of traits, so that Heller uses a multidimensional concept of giftedness (the 'Munich model' [13]), where giftedness comprises:

- intelligence (intellect)
- creativity
- social competence
- musical ability
- psychomotor ability/practical intelligence

Spotting the gifted

Given the preceding comments it is clearly not appropriate to suggest that there is a single, simple 'checklist' of characteristics of the gifted. Different definitions and perspectives on giftedness naturally lead to different views of what counts as giftedness. However, among the characteristics that have been proposed for gifted learners, [14 15] gifted learners may demonstrate:

- a strong drive for achievement,
- a willingness to exert themselves,
- perseverance
- a thirst for knowledge,
- inventiveness
- self-assurance,
- autodidactic tendencies – well developed ability to develop their own learning

The most able (i.e. 'highly gifted') may score less well on 'planning and organisation of work', and 'control of motivation', possibly a sign that they "do not need the usual...techniques for coping with" school work. [16] It has also been suggested that these very able students "prefer to work alone and not to cooperate in groups with classmates". [17]

The Nebraska Curriculum Manual for working with high-ability learners suggests there are eight 'great gripes' of high ability students: [18]

- No one explains what being a high-ability learner is all about-it's kept a big secret.
- The stuff we do in school is too easy and it's boring.
- Parents, teachers, and friends expect us to be perfect, to do our best all the time.
- Kids often tease us about being smart.
- Friends who really understand us are few and far between.

- We feel too different and wish people would accept us for what we are.
- We are overwhelmed by the number of things we can do in life.
- We worry a lot about world problems and feel helpless to do anything about them.

> **'A boy and girl had a tendency to delve back to the definitions of topics and their clarity of thought and verbal/communication skills were amazing to observe. They often countered an opinion by specifying a real life example. They also used phrases such as: 'suppose you' and sometimes posed hypothetical situations.'**
>
> *(Observation notes from an ASCEND session)*

How might 'giftedness in science' be characterised?

The notion of giftedness relates to high ability in an academic area (see Chapter 1), and doubtless there are some traits that would support high levels of attainment in any 'academic' subject. However the disciplinary nature of different subjects is both likely to lead to characteristic ways in which giftedness is realised in particular subjects, and (through particular interest in the subject matter) lead to some learners showing unusually high levels of attainment through a particular engagement with the subject or aspects of it.

Indeed, the work of Csikszentmihalyi reminds us just how much more can be achieved (and seemingly with little effort) when we are so engaged in an activity that we 'lose ourselves' in the task. Teachers will recognize how a lesson where we feel really engrossed will seem to 'fly by': sadly for many students in some lessons quite the opposite is true. Csikszentmihalyi argues that the type of intense concentration that comes with this high level of engagement (which he calls 'flow') allows us to think much more effectively than under more normal conditions. A learner engaged at this level may well demonstrate gifted characteristics that are not observed in other learning situations. [19]

A number of characteristics of giftedness in science have been proposed. [20 21 22 23] We might expect gifted learners in school science:

- To show strong curiosity about objects and environments; to seek explanations for the things and events they observe, often asking many questions, especially 'Why?'
- To show interest in collecting, sorting, and classifying objects
- To demonstrate (and sustain) high interest in investigating scientific phenomena
- To demonstrate intense interest in one particular area of science (e.g. astrophysics) to the exclusion of other topics.
- To show good powers of concentration

- To be easily bored by over-repetition of basic ideas but enjoy challenges and problem solving
- To have a tendency to make observations and ask questions
- To learn novel ideas readily: they can quickly understand models and theories
- To relate novel ideas to familiar ones, including the ability to make connections between scientific concepts and observed phenomena
- To move beyond the information given, remaining within the context in which it has been learnt
- To move ideas from the context in which the have been learnt to an unfamiliar context, e.g. linking school science concepts to knowledge and understanding developed outside of school
- To be dissatisfied with over-generalised explanations and inadequate detail
- To recognise and use formal scientific conventions
- To leap ahead or jump steps in an argument and detect flaws in reasoning of others
- To hypothesise readily, manipulate variables fairly and make predictions
- To suggest a variety of alternative strategies for testing predictions or gathering evidence
- To perceive rapidly the direction of an investigation and anticipate outcomes
- To identify patterns in data where the links are not obvious
- To want to quantify experimental results by counting, weighing or otherwise measuring
- To produce models - they may model mathematically
- To generate creative and valid explanations
- To use a more extensive scientific vocabulary than their peers when explaining things and events
- To reflect on their own thinking and learning
- To take on roles and exercise leadership within a group
- To be prepared to live with uncertainty.

As pointed out above, it is important to see a list such as this as indicators of the characteristics that gifted learners may show in science, and so as a guide to support planning teaching to meet their special needs. It is not appropriate to expect all gifted learners to match all these characteristics, or to match characteristics consistently on all occasions and in all contexts.

One feature of gifted behaviour in science relates to how students cope with the formal and abstract aspects of science subjects, something that many other learners find especially challenging. [24] For example, Fisher describes how a group of gifted primary pupils (c.10 year-olds) with an interest in science were able to discuss the gas laws:

> **"This desire to take an active part in discussion has led more recently to a consideration of the factors which affect the pressure of a gas, being treated in a semi-formal manner, and here was a powerful demonstration of the advanced ability to separate variables and exclude variables in the investigation of relationships. Preconceptions were dealt with in a more immediate manner and progress was very rapid; this topic involves mathematical concepts..."** [25]

Similarly, 'particle theory' is usually considered as a demanding concept area that many learners have difficulty coming to grips with. [26] This may be one area of science where gifted learners cope with the conceptual demands more readily. So in the 1960s, researchers at Brentwood College of Education studied gifted children from local junior schools who attended for a half-day per week, [27] to work with trainee teachers. [28] They suggested that such able upper primary children (at a time when science in the primary school was limited and often down to the teacher's whim) might well cope with the particle model of matter:

> **"There seemed no doubt, during a conversation of some duration with a ten-year-old group, that ideas of the particulate nature of matter were immediately available and ready for application in new situations. These concepts seemed to have been arrived at intuitively and as a matter of faith, (as indeed, in the final analysis, there is little available first-hand evidence for a choice between continuous and non-continuous material hypotheses)."** [29]

In a study of Greek 7th and 8th grade students, Georgousi, Kampourakis & Tsaparlis found that for the 'able' students

> **"submicroscopic concepts not only may be within their grasp, but also they may entice them and increase their interest in science. Such knowledge, then, can have its place, offered as an optional reading..."** [30]

There are, of course, many other highly conceptual and abstract ideas that are met in science. Teachers spend much time attempting to make these ideas more concrete and straight-forward for many learners. This is certainly sensible when introducing abstract and complex ideas, but gifted learners may well be ready quickly to tackle these topics in terms of more sophisticated and nuanced treatments. [31] It is to the nature of educational provision for the gifted we now turn.

CHAPTER 3: PROVISION FOR THE GIFTED

This chapter considers what type of educational experiences and activities are considered to best meet the needs of students who have been identified as gifted. It begins by reviewing the main approaches to meeting the needs of gifted learners in the curriculum, then turns to consider the features of activities and tasks that should be planned to challenge the most able learners in science classes.

Approaches to meeting the needs of the most able

The gifted, like all learners, need a curriculum that meets their needs, and challenges them. This may be as a special group provision, or as part of the differentiation of provision for a wider group of learners. Provision for the gifted could also include accelerated learning and enrichment. Within mixed-ability groups it may also be possible to consider the differentiation of roles among learners. It has also been suggested that gifted learners may benefit from being provided with mentors.

Curriculum acceleration

Accelerated learning means passing through the normal curriculum, but at a faster rate:

> **"Accelerated learning is being flexible and giving students school work that is in keeping with their abilities, without regard to age or grade. These students are allowed to progress throughout the curriculum at a more advanced rate than normal by grade advancement…"** [32]

This type of acceleration is relatively rare in the UK, although it is not unusual for schools to enter top-set pupils for some GCSE examinations early, e.g. at the end of Y10 or even earlier. Clearly, acceleration is a strategy that will only be successful if it is to be continued through subsequent stages of a learner's education. It has been suggested that "curriculum acceleration may be the only way for an educator to meet the educational needs of a high-ability learner, prevent academic underachievement, and prevent behavior problems caused by boredom, frustration, and anger".[33] However, in view of the difficulties of coordinating such an approach across different stages of the education system, it may seem that differentiation and enrichment offer preferred strategies.

Differentiation

Differentiation has been defined as "modification in content, process, and product based on the needs of the student". [34] Differentiation is a process of responding to the different needs of different learners. In one sense it is a real challenge for teachers, as the organisation of schools (timetables etc.) makes the class the prime unit for planning. In effect every lesson is '***n*** lessons in one', where ***n*** is 25-30 or however many students are present.

Students differ in many different ways, not just measured ability, so attempting to avoid the differentiation issue through 'setting' will only ever be a partial solution. Research also suggests that teachers feel obliged to teach top sets rapidly, limiting time for *explaining* ideas. [35]

Even with setting 'every class is a mixed-ability class': both because there is always a range within any set, and because individual learners will have a profile of strengths, even within a curriculum subject. Yet, research also suggests that teachers do not use differentiation strategies to the same extent in set classes, [36] which is perhaps understandable as a main rationale for setting is surely to make life easier for the teacher!

So differentiation is not something that only applies to teaching broad ability groups: as Stepanek comments,

> **"differentiated instruction…is a continuous process of learning about students' needs and interests and using that knowledge to guide instruction"** [37]

Common forms of differentiation are *by task* (setting different work) or *by outcome* (expecting different levels of attainment from different students undertaking the same task). Both of these approaches have limitations in classroom teaching, and a common alternative strategy (often used instinctively in real time, so not always recognised) is differentiation *by support* – where different students receive different levels and timing of support according to need. All teachers do this to some extent, and it requires good awareness and skill to be an effective strategy - but it has the advantage that the teacher does not have to assume in advance which students will excel or struggle on a particular activity (unlike differentiation by task).

It has been suggested that the English National Curriculum (NC) structure, with its large number of topics to be 'covered' does not provide a very helpful context for developing suitable learning opportunities for gifted learners. However, even within such a system, there are ways to plan teaching (using the notion of key ideas, and even NC levels) that can support progression for all learners. [38]

Enrichment

In some curriculum contexts (e.g., many would feel, the English NC) enrichment may be needed to allow the most able learners to access suitable provision for the gifted. Enrichment has to be different *in kind* from the standard lesson activities experienced by students:

> **"Enrichment basically refers to study, experience or activity which is above and beyond the normal curriculum followed by other children of the same age. There is enrichment by depth, where a topic is covered more fully; and there is enrichment by breadth, where broader and more varied topics are explored…children who finish their work quickly should not be given more of the same work to complete. Not only is that not a form of enrichment, but it is precisely those children who least need to do more of the same work as they have already grasped the principles involved. With enrichment the gifted children remain with their own class."** [39]

Enrichment is therefore a form of *individualized* learning ("where the child has work which is particular to that child") rather than just *individuated* teaching ("where a child interacts with the teacher on an individual basis"). [40] Enrichment activities should be specifically planned for the gifted child, rather than being taken from the programme of work later in schooling. In the UK context, "schools are encouraged to include different curricular provision, either within or alongside the statutory curriculum". [41]

Sternberg argues that the type of provision that is appropriate (acceleration versus enrichment) depends upon what we value:

> **"If we value rapid learning, then acceleration makes sense. If we believe that what matters is the depth or care students take probing into what they learn, enrichment will be preferable."** [42]

Compacting the curriculum

A key approach that can help maintain interest and motivation of gifted students is compacting. This is an extension of the principle of diagnostic assessment that all teachers are encouraged to use to avoid spending precious class time on material that students have previously mastered. Compacting occurs "where a child has mastered an area or a skill in a subject, as assessed by a pretest, then… such a pupil is allowed to miss work in areas in which he is already competent, and use the time 'saved' on extension activities". [43] There are three stages to compacting [44]

- pre-testing - identify content or skills already acquired
- elimination of surplus materials from the scheme of work
- replacing the surplus materials with alternative, suitably challenging, materials

Among the reasons that compacting is considered suitable for gifted learners is that it is thought to satisfy the hunger for more in-depth learning than normal school fare may provide (see chapter 2), and so avoid boredom; and that it can encourage independence in learning (see Chapter 5). [45] However, compacting requires teachers to plan learning on an individual basis, something that is only likely to be successful where learners can already demonstrate a level of self-regulation of learning,

> **"Curriculum compacting is a system designed to adapt the regular curriculum to meet the needs of high-ability learners by either eliminating work that has already been mastered or by streamlining work that may be mastered by students at a quicker pace than that of their peers. Curriculum for the high-ability learner should be compacted in those areas that represent the student's strength."** [46]

Developing science activities for gifted learners

Suggestions for designing learning activities for gifted science students are often linked to those areas of strength that such learners are believed to show, which are also seen as particularly desirable aims of educational activity:

- Higher level thinking
- Creativity
- Independence in learning
- Group-work
- Inquiry skills

These themes are interlinked, as will become clear in the following discussion.

Higher level thinking

The notion of a hierarchy of thinking skills is well established, with skills labelled as analysis, synthesis and criticism or evaluation seen as being more demanding than those of recall, comprehension and application. [47, 48] Teaching that requires learners to use the 'higher level' skills (see table 3.1) will be more demanding for students. Clearly teaching will require all learners to use thinking skills from across the spectrum, but it is recommended that when working with the most able, a profile much richer in the higher level skills is appropriate.

Level	Descriptors of typical activities
Create	Generating, planning, producing
Evaluate	Checking, critiquing
Analyze	Differentiating, organizing, attributing
Apply:	Executing, implementing
Understand	Interpreting, exemplifying, classifying, summarizing, inferring, comparing, explaining
Remember	Recognizing, recalling

Table 3.1:
Hierarchy of thinking skills, after Bloom as revised by Anderson & Krathwohl

Ideally, incorporating appropriate demands into science teaching needs to be considered at a departmental level when planning schemes of work, and when designing a departmental assessment policy. [49]

The literature contains a range of suggestions of how to enrich teaching in terms of higher-level thinking. [50] [51] [52]

Questioning types:

In terms of the questions asked in class: those directed to the most able should require the learner to analyze, synthesize or evaluate.

Making thinking explicit:

Learners should be asked to be explicit when using inductive and deductive reasoning: being encouraged to cite evidence, or sources of hunches, and explain the logic used in drawing conclusions (see Chapter 5). Teaching can model appropriate thinking strategies for students.

Pacing learning:

Whilst the most able are often able to learn rapidly, integration of ideas is encouraged by having extended projects with longer-term deadlines.

Conceptual learning:

Science learning should be focussed on the underlying concepts ('deep content'), rather than specific facts. Teachers can look to increase the level of abstractness when teaching the gifted - something science lends itself to, and where often in teaching we aim to help make abstract ideas concrete for many learners. Similarly, where teaching often involves deliberate attempts to simplify complex ideas without distorting them, 53 the gifted may benefit from tackling intentionally complex learning materials. Such teaching can help students to identify rules, principles and relationships.

Encouraging integration:

offering opportunities for learners to make connections across disciplines as well as across topics. 54

Figure 3: *Creating new links: the scientific analogy gam*

Creativity

Activities designed for the most able should look to provide opportunities for them to demonstrate and develop their creativity. [55] [56] [57] We know that intuition and visualisation skills are strong in many creative scientists, [58] and we should plan gifted science education activities with this in mind. [59]

Open-endedness:

Questions that admit a wide range of possible responses can encourage critical and creative thinking. Similarly, open-ended tasks allow learners to respond creatively.

Encourage novelty:

It is very easy to criticise new ideas, especially where they have obvious faults. However, the novelty can in itself be valued (after all, many very successful new ideas in science and technology were flawed in their initial form). Students can be encouraged to produce ideas and products that challenge familiar ideas and ways of working.

Problem-solving:

A problem is more than an exercise (where familiar ideas and processes are rehearsed). A genuine problem requires students to develop and organise their knowledge into a new form to produce a solution. Authentic problems may motivate gifted learners, as they will see some genuine purpose to the work. (The gifted cohort at the author's primary school were assigned tasks such as finding out how many paving stones would be needed around the new outdoor pool, and finding the distance around one circuit of the route for a fundraising walk. Presumably, the answers were later checked by adults!)

Complex Productions:

Work for the gifted should offer them the chance to produce some type of outcome. This will be an authentic activity if there is a genuine audience for the product. [60]

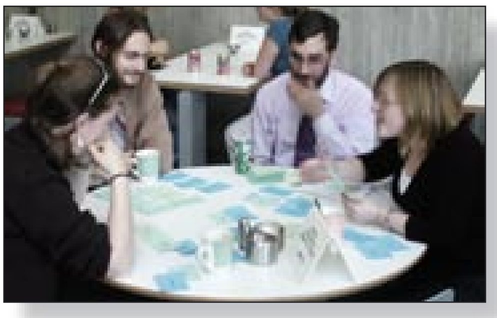

Figure 4: *The analogy game: not just challenging the students!*

Independence in learning

One aim of education is to produce effective learners - students who are able to direct and regulate their own learning. Within a school context there is often a tension between this aim and pressures on the teacher to both retain classroom authority and 'cover' a set curriculum. However, these aims need not be at odds, and students who are able to make sensible decisions about their own learning (e.g. when to move on to the next task; when some remedial input is indicated) can make life easier for the teacher, especially where teaching sets out to match the needs of different learners in a class.

Gifted students are likely to have developed greater metacognitive knowledge (i.e. knowledge of their own thinking and learning – see Chapter 5) and skills than many of their classmates, and some may be effective autodidacts (i.e. self-teaching) outside of school – used to planning and evaluating their own learning when following-up their interests. The special needs of the gifted in classes makes it sensible for teachers to both make use of, and seek to develop, their ability to regulate their own learning. This does not mean the teacher should abdicate responsibility. Rather the teacher should delegate some 'measured' degree of responsibility to the gifted student to work as an independent learner, whilst monitoring whether the degree of independence should be modified.

A number of suggestions are made in the literature for encouraging independence in learning. [61 62 63]

Choice:

It is suggested that students should be given some level of choice in selecting activities and approaches.

Technology:

ICT can be used as a learning tool to allow gifted learners scope for independent learning.

Depth of study:

Gifted learners can be encouraged to undertake extended studies that allow them to follow-up interests in some depth.

Self-evaluation:

Gifted learners should be involved in evaluating their own performance against appropriate criteria. One simple approach that can be used is 'most difficult first'. This is used where the class is working on a graded set of exercises (allowing most students to develop understanding and competency as they move through the questions of gradually increasing difficulty). The most able students can be asked to attempt the most difficult questions first. If they complete these successfully, then they move on a new activity (preferably self-selected) and are not expected to work through the less difficult questions. (This may be compared with the process of curriculum compacting discussed above).

> **'Student, S, quickly took the lead organizing the cards and reading them out . . . She had a clear idea of what she wanted to do and how she was going to do it . . . She made sudden, snap decisions . . . her classification was fairly sound'**
>
> **'They worked quickly, in a seemingly frenzied and unstructured way . . they were fired up and excited'**
>
> *(Observation notes from an ASCEND session)*

Group work

In reviewing the nature of giftedness in Science, Gilbert suggested that many gifted learners would be able to take on roles within groups, and offer group leadership. [64] This in turn, provides opportunities for learning from activities,

> **"Research indicates that cooperative learning, if handled properly by a skillful teacher, enhances the learning of high-ability students"** [65]

Classroom talk can be a major means by which learners share, develop and challenge ideas. This relies upon the talk being on task, and at a sufficient level of sophistication. In particular, talk that supports effective learning will have a 'dialogic' nature, that is it will be about sharing perspectives, and questioning and exploring ideas, rather than 'telling'. Effective science teachers ensure that this type of talk features in classroom dialogue. [66] When students are encouraged to engage in this type of talk, that facilitates learning, they are able to demonstrate their potential for thinking about ideas in science. [67]

Figure 5: *Making a point*

Peer tutoring

This could indeed be seen as a means of structuring learning to enable informal peer tutoring, where students teach each other. If peer tutoring were simply seen as making use of the presence of more advanced students to help their less advanced peers, then this would be a questionable activity: children go to school to learn, not to teach. However, teachers' own experiences suggest that they can develop a much deeper understanding of their subject through the process of preparing to teach others, 68 and having to explain an idea carefully to another who does not yet understand it can certainly be the basis of a useful learning experience.

Figure 6: *Explaining to peers*

> **"remind me how psychiatry is different from psychology"**
> **"psychiatry tends to use counselling and stuff, psychology is the study of the way the mind works, psychiatry is definitely to do with (dealing with) mental disorders"**
>
> *(Dialogue from an ASCEND session)*

Inquiry skills

Inquiry is fundamental to science, although genuine inquiry (rather than practising formulaic 'fair testing') is perhaps not as common in many science classrooms as many of us might wish. [69] However, inquiry is considered to be very suitable for motivating and challenging the most able [70] [71] [72] [73] – and potentially offering opportunities for higher level thinking, creativity, independence in learning and group-work. In the period since the National Curriculum was introduced in England, genuine inquiry in school science has tended to be downplayed as students needed to demonstrate competence in the more limited competencies required for 'fair testing' (for Sc1 'investigations' that have contributed to GCSE examination scores). [74] In some other countries it is common for students to develop open-ended projects for science fairs, and demonstrate genuine inquiry skills (and sometimes make genuine scientific contributions), [75] although this usually involves a degree of 'mentoring' that is somewhat different from the typical teacher-pupil relationship that can develop within the scope of most classroom contexts. [76] However, in the UK, opportunities for extended authentic projects have in recent years been mostly limited to those involved in enrichment activities though after-school science clubs, or able to attend special Summer schools. [77]

Although it is widely accepted that much practical work in secondary schools has become "a tedious and dull activity for both students and teachers", [78] there is much potential in using practical science to engage and challenge gifted (and other) science learners.

Problem-Based Learning:

Inquiry allows students to investigate authentic problems, in 'real-world' contexts, 79 and so can motivate able students who may become genuinely interested in finding answers and solutions.

Design:

Experimental design allows students to demonstrate creativity, as well as apply logical thinking.

Drawing conclusions:

Inquiry provides opportunities for learners to draw their own conclusions, identifying patterns and making generalisations.

Appreciating method:

The nature of science is considered to be a suitable theme for engaging and challenging the gifted in science. Authentic inquiry offers opportunities for appreciating the nature of scientific method, as well as the subtleties and complexities of designing experiments and the logical difficulties in drawing sound conclusions form practical work in science. Indeed, the nature of science was chosen as the main theme for the ASCEND programme, and is the theme of the following chapter.

CHAPTER 4: THE NATURE OF SCIENCE

This chapter looks at one suitable theme for planning provision for gifted learners in science lessons: the nature of science. As well as being a central part of the science curriculum ('scientific investigations', 'how science works'), this theme offers a number of avenues for developing activities to challenge the most able learners.

The preceding chapter offered ideas from the literature on approaches to planning teaching and learning for gifted students in science classes. Two particular themes around which gifted science provision may be organised are *understanding the nature of science* and *developing metacognition*. These are not the only possible suitable themes, but they provided the basis of the SEP supported ASCEND project that is discussed in chapter 6 (and which led to the development of the teaching resources included with this guidebook). Metacognition (i.e. thinking about thinking) is explored in the next chapter, and the present chapter discusses how the nature of science can provide a basis for challenging the most able in science classes.

The nature of science

One aim of science education is that learners should come to understand something of the nature of science:

> **"Science educators have realised that major trends in 20th century scholarship on science itself…are important for science education. But much science teaching seems not to have absorbed this lesson."** [80]

Appreciating what science is, and in particular how it operates, is important for those students who aspire to work in scientific fields, and is just as important to their peers who do not. Being a responsible citizen in a modern technologically advanced democracy means having some idea how scientific advice (about global warming, about nuclear power, about genetically modified foods, etc.) is derived. [81] At the minimum, this provides some basis for weighing up information presented in the media, and so informing decisions about lifestyle, voting preferences, making major purchases etc.

As Gilbert has pointed out, the history and philosophy of science offers a rich source of ideas for developing the most able learners in science. [82] There are a number of reasons why we might expect the nature of science to offer a theme for planning gifted science provision:

Logic

One key aspect of scientific activity is the application of logic. Both the design and interpretation of experiments involves the application of logic, and although often in school science this process is presented as simple and straightforward, [83] there is scope for challenging very able students in this area. Epistemology - how we come to knowledge - is a key aspect of the philosophy of science, and offers a useful and engaging context for stretching gifted learners. Appreciating how and why scientific models succeed each other can provide a theme that will fascinate some able students.

Key aspects of how science progresses revolve around the nature of argumentation, [84] and the development of models and explanations. These themes provide excellent foci for engaging gifted learners. A team based at King's College London, have developed approaches to teaching about scientific argumentation based on the analysis of the philosopher of science Stephen Toulmin, [85] and materials based on this work are available in the SEP publication '*Teaching Ideas and Evidence in Science at Key Stage 3*' (http://www.sep.org.uk/publications.html). [86]

Complexity

The logic of scientific discovery is not the only aspect of science that is generally simplified for discussion in school science. Indeed it is quite necessary that current scientific knowledge is transformed into suitable curriculum models (the target knowledge judged to be suitable for the learners), and then transformed again by teachers who use various models, metaphors, analogies etc., to 'make the unfamiliar familiar' and help learners understand new ideas. The detail and sophistication of current scientific knowledge about photosynthesis, or ecosystems, or atomic structure, or polymers, or transformer design, or galactic structures makes that knowledge too difficult and too vast for school students. The process of forming 'curriculum models' sets out simplifications that offer an 'intellectually honest' but attainable understanding of such topics suitable for classroom teaching and learning.

Such simplifications are as necessary for gifted learners as their peers, but the 'optimum level of simplification' [87] will be different - just as we expect different depths of understanding of photosynthesis or polymerisation at different stages of schooling. In some cases, teachers are frustrated because many students struggle to cope with more complex topics (e.g. understanding ionisation energy in A level chemistry [88]). Many of the topics already met in the school curriculum have the potential to offer gifted learners continuing intellectual challenge as they are understood in increasing degrees of sophistication. For example, ecosystems may be modelled at many levels of complexity, allowing great scope for differentiation and progression.

Integration

A key aspect of science is a set of beliefs about the nature of knowledge and the consequent values that inform scientific work. An assumption that we can model the world in consistent ways underpins any attempt to derive knowledge through logical processes (see above), and a heuristic expectation that simpler explanations are more likely to be 'true' (or reliable, or at least useful) than unnecessarily convoluted ones informs much decision-making in science. Moreover, the expectation of consistency leads to an assumption that ultimately different branches of science should be coherent. Indeed most advanced areas of scientific knowledge are ultimately built upon more basic theories and principles that are shared across much of science (such as conservation of energy, chemical elements, etc.). Part of the wonder of science is how it is (in principle, if not perfectly in practice) an extended network of interlinking ideas. Perhaps science teachers and other scientists take this for granted, but this is not the case in all academic disciplines. If this interlinking and coherence is a part of the nature of science, then we should aim for conceptual integration as a key outcome of student learning of science. [89] Yet, in practice, much science learning seems to be piecemeal, which not only makes it harder work for learners, but also means these learners are missing one of the most intellectually satisfying aspects of the subject. As Gilbert points out, making connections within and between topics and subjects is something that we should expect of gifted science learners. [90] This is an important part of learning science for all students, but the most able can be set tasks where they explore and discover those links for themselves.

In academic research and in industry, much scientific research is carried out in teams, and increasingly in inter-disciplinary teams where different specialists contribute their own expertise. This team-work is part of the nature of science, and something we would want learners to appreciate. Gifted learners may also be able to appreciate the evolution of the scientific disciplines – for example, that the division between chemistry and physics is historically contingent as much as a reflection of some fundamental distinction in nature. [91]

Science as a human activity

Whilst many gifted students may be fascinated by the logical, complex, coherent nature of scientific knowledge, others will be attracted by the personal side of science. This is especially important as it is believed that secondary age girls are often more 'person-oriented' than boys, and may be much more engaged in science when it has a human face. [92] There is no sleight-of-hand in this, of course, as science is a human activity, carried out by people.

The history of science offers many examples of scientists and their work, which can act as context for learning about

- how scientific ideas develop as new ideas and evidence become available

as well as providing a basis for appreciating

- the tentative nature of scientific knowledge; and
- the significance and status of scientific laws, principles, theories and explanations.

Science as something communicated

The communication of science is a key aspect of the 'business' of science (as recognised in the revised KS4 curriculum from 2006), as even the most insightful idea only becomes part of science once debated and accepted by other scientists. Communication can take many forms, and involve a range of symbolic tools (modelling through graphs, flow charts etc.). Tasks involving the communication of scientific ideas and findings allow students to develop their communications skills, and provide scope for creativity and imagination (e.g. creating new analogies to explain an idea).

Science as part of society

Part of the rationale for studying science in school, especially for the majority who will not become professional scientists, is the important roles that science and technology play in technologically advanced democratic economies. [93] Students need to understand that scientists (*per se*) can only make decisions about what counts as current scientific knowledge, and that decisions about the application of science are influenced by 'political' processes. Students passing through school will later have roles to play in such processes, by their purchasing decisions as consumers, and through their engagement (or not) in political activity (if only voting in elections). Understanding the relationship between science and society provides further scope for learning about complexity, further linking between domains, and more opportunities to relate the science to people.

Whereas thinking about the logic of scientific knowledge development requires applying (largely) logical considerations, considering socio-scientific questions involves not only weighing the relative merits of inconsistent 'scientific evidence', but also the application of other types of values (moral, rather than 'logical') to evaluate complex questions. [94]

Science as a collaborative activity

Science involves both collaborative and competitive processes, and both are significant in understanding how science progresses. However, the common presentations of scientists in the media have traditionally emphasised the scientist as working alone (or with an assistant who just assists). In practice, most significant scientific work for many decades has been undertaken within research groups where there is extensive sharing and critiquing of ideas even when scientists work on 'individual' projects. (An exception, an independent scientist who has made major contributions, would be James Lovelock who travelled the oceans surveying the spread of atmospheric pollutants).

School science offers many opportunities for group work, and most of the ASCEND activities were organised around groups. As Gilbert has pointed out, many gifted students should be able to take on roles in groups, offering leadership, evaluation, conciliation etc. [95] There is some evidence that gifted learners often prefer to work alone, unless they reach a point where they 'get stuck'. It is important, therefore, that in group-work, the most able students are given tasks that require them to collaborate: either by having explicit responsibilities within the group itself, or through the level of demand of the task.

If the role of the gifted student is as a tutor for peers, as suggested above, then it is important to ensure that the student is supported in tutoring in ways that provide learning opportunities for both partners.

CHAPTER 5: METACOGNITION AND INDEPENDENT LEARNING

This chapter explains what 'metacognition' is, and why it is important in learning. In particular, the chapter explains why developing metacognition should be seen as a particular goal of science education for gifted learners. The theme of metacognition is linked to the ideas of independence/self-regulation in learning, and is needed if students are to be given responsibilities through 'assessment for learning'.

Metacognition: thinking about thinking

Metacognition is the name given to the ability to be aware of, think about, and manage one's own thinking processes. It was introduced as a subsidiary theme for the ASCEND project, as it was considered that gifted learners would need well-developed metacognitive skills to work optimally.

Metacognition can include rather basic levels of thinking about thinking: 'that was hard', 'I should be able to do this, it's primary school work', 'I wasn't really concentrating on my work just then'.

However, it would also include a more sophisticated awareness of one's cognitive strengths and weaknesses, allowing decisions to be made about what tasks are likely to be achieved, how long a piece of work might take, when help is likely to be needed.

Metacognitive skills would include the types of abilities involved in solving non-trivial problems, such as being able to break down problems in simpler steps, monitoring progress, recognising where errors might be made, and incorporating suitable checks, etc. [96]

Self-regulated learners

Independence in learning, or the ability of a learner to be 'self-regulated' is clearly a goal for all our students: we want them to leave school with life-skills that make them effective learners who know how to research topics for themselves.

Developing 'thinking skills' is seen as being central to the school curriculum, [97] and science clearly has a major role to play in this agenda.[98] Thinking skills include logical thought, creativity, etc., but also metacogtnitive skills.

Some schools already support students in developing metacognition through teaching about study skills: explaining about 'active' learning, effective revision technique, learning styles, and so on. [99] Basic knowledge of how perception, attention and memory work can help learners understand their own cognitive processes.

Assessment for learning

In recent years there has been a significant emphasis on shifting the focus of much assessment of students' work from summative assessment (awarding grades at the end of the learning process) to formative assessment – assessment to inform the learning process. In particular, teachers are encouraged to adopt the processes of 'assessment for learning' (AfL) and a key feature of this is involving learners in monitoring their own learning. [100] Teachers are asking students to mark their own work against marking criteria, undertake peer review, suggest their own targets for improving their work, and so forth.

Clearly, involving learners in this process effectively both presupposes a level of metacognition, and provides opportunities for students to develop greater insight into their own strengths, weaknesses, learning styles, and so on. Some of the AfL techniques recommended to teachers will help students to learn to better regulate their own learning, by developing their metacognitive knowledge and skills.

Metacognition and the gifted

In planning the ASCEND project it was felt that metacognition should be an additional focus (along with the nature of science). Such a focus would be especially useful in developing gifted provision both from a consideration of the practicalities of teaching gifted students in mixed ability settings, and in terms of the particular characteristics of gifted students.

The former consideration was the role of *differentiation* in effective teaching. Even in top sets there is likely to be a considerable range of ability, so that exceptionally able students would remain exceptional among their able but less exceptional peers. Effective teaching across wide ability ranges requires effective differentiation (through one means or another) by the teacher, and for most forms of differentiation to be effective, learners have to be able to respond by taking *some* responsibility for regulating learning. This is likely to be especially so for the most able who are 'outliers' in the class population, and where teachers may assume a capability for high levels of independent learning. It was decided that ASCEND would be set up to assume (and test) the notion that more able students could indeed take responsibility for organising and monitoring their own progress on extended tasks.

The latter consideration was a recognition that

- effective students usually have already developed high levels of metacognition, and
- that exceptionally able learners are sometimes autodidacts who are able to largely teach themselves with little external input.

One of the characteristics that it is said can be *expected* of highly able students is that they show a high level of independence in their learning. [101]

It was reported above that one of the common complaints reported from high ability students is that "no one explains what being a high-ability learner is all about-it's kept a big secret". [102] It was decided to include an activity in ASCEND about learning and studying in one of the early sessions in the programme. Although some exceptional learners do find effective ways to 'teach themselves', this does not imply that all gifted students will be effective autodidacts. Just as motivation to be a good teacher does not negate the need for effective teacher education, a desire to learn, and a willingness to be a self-regulated learner, may not by themselves provide the metacognitive awareness to become an efficient self-directed learner.

Metacognition and the learning (and doing) of science

In learning science, students are often expected to restructure their thinking about topics. It has been suggested that this can be achieved most effectively when students are able to 'stand back' and reflect on their own thinking. Studies into the learning of science have highlighted the importance of metacognition. [103] [104] [105] [106] [107] It can help students if they can:

- recognise their own way of thinking about a topic, and explore how this differs from the version offered in school science;
- appreciate how their own thinking about topics is changing as they learn;
- recognise the way they think about science in terms of models, especially when they are using several distinct models for thinking about the same topic (which is common practice both among students, and practising scientists).

These are, of course, skills that scientists themselves need if they are to undertake creative work that develops new theoretical insights. Indeed, there are some important areas of scientific thinking where the role of metacognition is not fully understood, but which are currently being explored for their significance to learning science, and to developing the skills needed for a productive scientific career:

- Scientific visualisation – learning to 'see' (and mentally model and manipulate) the various structures and systems represented in scientific imagery (e.g. molecular structures) [108]
- Thought experimentation – the ability to run mental simulations of physical (or biological) systems [109]
- Scientific intuition – enabling, for example, the ability to identify and use analogies between scientific fields [110]

These are the types of abilities we might expect to be limited in many secondary students, but students who are gifted in science may well either already posses precocious skills in these areas, or at least have the potential to develop them. Certainly, students given the opportunity to apply such thinking processes during their experience of school science will be provided with an authentic feel for scientific thinking.

CHAPTER 6: ASCEND – A SCIENCE ENRICHMENT PROGRAMME

This chapter discusses the ASCEND project, which developed an after-school science enrichment programme for 14-15 year-olds using the themes of understanding the nature of science and developing metacognition. The activities developed for this programme are introduced in the next chapter. The original teaching materials used are provided on the accompanying CD-ROM.

> **'We think that science is . . . well cool yeah . . . it's why popcorn goes pop and not spat'**
>
> *(From dialogue during an ASCEND session)*

Introduction

ASCEND – Able Scientists Collectively Experiencing New Demands – was a project for able and enthusiastic secondary science students using the nature of science as a starting point for developing challenging tasks for gifted science learners. [111] The project involved a programme of enrichment activities held during after-school sessions at the University of Cambridge for students in the schools that comprised the secondary 'Federation' of schools in the City of Cambridge. After informal discussion with local schools, it was decided to work with pupils in Y10 (i.e. 14-15 year olds in the year before decisions were made about college subjects and applications). The Comprehensive Schools in Cambridge were invited to nominate students who would be:

- able enough in science to be ready to be challenged;
- interested enough in science to want to attend after school;
- and able to attend regularly.

Although the formal invitation did not specify that students needed to be on the school's gifted register, the informal discussions which preceded the invitation were couched in terms of challenging gifted learners in science. As discussed in Chapter 2, there are difficulties in the way 'gifted' is defined in percentile terms in official UK policy guidance. Clearly the intention was not to include gifted students who were not interested in spending their free time doing more science, but equally not to exclude students that the teachers felt would benefit from challenges but were not technically on the 'gifted register' because they had not performed well enough in formal tests.

Part of the logic of working with several schools was to ensure there would be a 'critical mass'. By definition most schools only have a small number of exceptionally able students in a year group (indeed one of the Cambridge schools declined to participate on the grounds that it had no suitable students), and ASCEND would allow these to meet and work with similar-minded individuals from other schools. One of the complaints commonly heard from high-ability students is that 'friends who really understand us are few and far between'. [112]

Figure 7: *ASCEND was a chance to work with new friends from other schools*

The programme was also intended to show how, *in principle*, several schools could work together to share responsibility for joint provision (although *in practice* the University partner took the lead in planning, organising and running the programme). This reflected the model used in the Excellence in Cities programme, where

> **"The schools within each partnership are normally grouped together into 'clusters' of 3 to 8 schools with a Lead Co-ordinator who is responsible for gifted and talented provision within each cluster. Each cluster of schools has formed a network with a range of external partners such as higher education institutions, libraries, museums and businesses to support the provision of out of school hours activities."** [113]

The programme was organised to run approximately fortnightly (during school terms) at a suitable time to allow students from the participating schools to walk, cycle or otherwise get to the Faculty of Education. The decision to hold the sessions in the University was a deliberate one: as well as being 'neutral' ground, this would be an adult environment, where the students could be treated as if conference or course delegates. To this end, the sessions were arranged such that they started with a thirty-minute window for a conference style registration during which delegates could take refreshments and socialise in the Faculty café. [114]

Figure 8: *Refreshments (and socialising) during the registration period at the start of an ASCEND session.*

The group then moved to teaching accommodation for a ninety-minute academic session. The sessions were led by the author, supported by a team of teaching/research associates, with school science staff having an open invitation to attend and become involved. The Faculty teaching team were all science education specialists – science teachers in training, or graduate research students.

Figure 9: *Support was available for students – when needed*

Four of the City comprehensive schools nominated students for ASCEND: Chesterton Community College; Netherhall School and Sixth Form College; Parkside Community College; and St. Bede's Inter-Church Comprehensive School. The total number of delegates from the four schools was about thirty, although not all were able to attend all seven sessions. The sessions were staffed by a group of about a dozen graduate assistants: these were science education research students and trainee science teachers who had all volunteered to be involved in the project. Some teaching staff from the schools came and observed or joined in some activities. Each session started-off with a short general introduction to that day's theme, normally followed by the delegates breaking-up into groups, and usually spreading among several adjacent teaching rooms to work on the set tasks.

A group size of around four was employed. In order to encourage mixing, it was specified in the first few sessions that each group should include (a) both genders, (b) students from more than one of the schools.

Figure 10: *Students were encouraged to work in mixed-gender groups*

The ASCEND activities

Two key themes for ASCEND were "The nature of science" (see Chapter 4), and "metacognition" (see Chapter 5). The former was selected because

a) it was considered to be an area where standard school provision was often weak;

b) it offered a relevant theme which would not simply duplicate school studies;

c) it was considered to offer suitable opportunities for challenging the most able.

In designing the activities, an attempt was made to provide contexts that would link with and support school learning, but without simply repeating or pre-empting work that the delegates would meet in school science.

A set of activities was designed for the ASCEND programme with a number of principles in mind. Firstly, as discussed in the previous chapter, the main organising theme would be aspects of the nature of science, with a subsidiary focus on metacognition. Secondly, most of the activities would be based around small group work, partly because being able to take on roles within groups is believed to be one characteristic of gifted learners in science (see Chapter 2). This also provided us with the ability to observe the students at work. The third key principle was that the work should be challenging, and so a minimum of guidance was provided in terms of exactly *how* to carry out activities. The delegates would be given tasks with overall aims, which they needed to plan and organise - and they also had to consider how they would evaluate their own achievements. In this way the 'default assumption', which was revisited during the project, was that when placed in a suitable, adult, learning environment, and offered responsibility for regulating their own learning, the delegates would be able to rise to the challenge.

In designing the activities, an attempt was made to provide contexts that would link with and support school learning, but without simply repeating or pre-empting work that the delegates would meet in school science. The activities devised (and described further in Chapter 7) were based around the questions:

How do we decide if some activity is, or is not, scientific?:
Exploring the criteria we used to define what is, and what is not, a science

How do we learn?:
The science behind learning, and how it can inform study habits

What makes a good scientific explanation?:
The criteria for a good explanation in science

Can we identify patterns in data?:
A practical activity looking to identify a scientific law

Can we learn from computers?:
Using independent learning materials designed to support learning about A-level Physics

How do we produce new scientific knowledge?:
Exploring the work of famous scientists in terms of simplified 'philosophies' of science

How do science specialists work together?:
Developing a model of plant nutrition by synthesising ideas from biology, chemistry and physics

Why do scientists believe in evolution?:
Exploring objections to evolution by considering the argument for natural selection

What is it like?:
A card game encouraging players to find analogies between scientific concepts and everyday ideas and phenomena

How do we evaluate scientific models?:
Comparing two particle models, and two models of ionic bonding, in terms of how well they can explain phenomena / properties

Figure 11: *Working with Level 3 (A level) Physics materials*

The computer-based learning activity was not primarily related to the nature of science theme, but was an opportunity to work with some National Learning Network (NLN) materials developed for independent learning of physics in the post-16 sector. [115] A report into the adoption and implementation of the NLN materials found that,

> **"for the majority of the students we met, the appeal of e-learning lay in three main areas: The value of multimedia presentation; The pace and manageability of learning; The scope for self assessment and feedback." [116]**

Clearly the second and third of these points are directly relevant to planning provision for the gifted, who may wish to work faster than many classmates, and may be ready to demonstrate greater independence in their learning (Chapter 5).

The 'learning science' activity was partly intended to inform the development of metacognition, but - in common with a number of other activities - also involved a modelling activity, something recommended for challenging gifted learners in science. [117]

CHAPTER 7: THE ASCEND ACTIVITIES

This chapter provides outlines of the ASCEND activities. For each activity, a brief introductory outline of the purposes and nature of the task is provided. A more detailed account of the activity, and the use of supporting materials is provided on the CD-ROM, and the outlines in the chapter are designed to help teachers decide if and when they might wish to access the more detailed account.

This chapter presents brief outlines of the activities developed and piloted through the ASCEND project. Most of the activities discussed are based around resources included on the accompanying CD-ROM, in a form that allows the classroom teacher to select, edit and modify materials for their own classes.

For each unit, there is a brief description of the nature of activity, and the rationale for its place in a programme of science enrichment.

The outlines here are intended as tasters, acting as 'abstracts' allowing teachers to decide if they would wish to find out more about that activity. A more detailed account of each activity, along with supporting materials, can be found on the CD-ROM. The activities are numbered 1-10, and the CD-ROM has corresponding numbered folders.

So, to find the more detailed account of Activity 1, you should access the 'Activity 01' folder on the CD-ROM, inside which there is a file 'Activity brief 01' and further folder containing supporting materials. Open the file 'Activity brief 01' for more information about the activity including guidance on how the materials may be used, and a listing of the related resources included on the CD-ROM.

CD-ROM: SEP Enriching School Science

Folder: Activity 01

- **File:** Activity brief 01
- **Folder:** Activity 01 materials

Folder: Activity 02

- **File:** Activity brief 02
- **Folder:** Activity 02 materials

Etc.

Box 1: *Structure of the CD-ROM*

All the activities were designed with gifted and able upper secondary (KS4) students in mind. All have been piloted with able Y10 (14-15 year-old) students during the ASCEND project.

It is hoped that many teachers may feel that some or all of these activities may provide a useful basis for challenging lessons for their own students, or at least be useful as a source of ideas for lesson activities.

ACTIVITY 1: WHAT IS SCIENCE?

This activity allows students, working in groups, to explore their criteria for considering whether an activity is part of science.

This activity concerns the fundamental question of 'what is science'. Whilst a basic question, it is certainly *not* a trivial one. In the philosophy of science, this is called the 'demarcation' question, i.e. distinguishing science from non-science, and there is neither a simple clear distinction, nor a consensus!

The activity is based on a card sort, which allows students to classify activities as 'science' or 'not science' (or 'not sure'), and through this process make their tacit criteria (and prejudices!) explicit. It is expected that although some of the cards should offer fairly uncontroversial activities, there is likely to be lively discussion about others.

The activity has three stages:

Part a) sorting the activity cards
Part b) making criteria explicit
Part c) comparing with another group

The tasks require students to evaluate activities according to both their own criteria, and by applying criteria that another group has attempted to make explicit.

ACTIVITY 2:
IS THERE A METHOD TO SCIENCE?

This activity introduces three models of 'how science works', and asks students to apply the models to historical case studies.

This activity concerns a key feature of the nature of science, which is the notion of a 'scientific method'. This has been (and continues to be) a very contested area within the philosophy of science, so it is not possible to offer a single prescription for how science can (or should) proceed. This type of complexity and lack of a closed answer should appeal to many gifted learners.

The activity introduces some basic ideas from the philosophy of science by proposing three models of ideas about how science works. These are simplified models, but nonetheless offer an authentic taste of the issues involved.

Students are asked to work in groups to discuss how historical sketches of the work of scientists support (or not) three models of the scientific method:

The three models presented are:

Model 1 – Induction
Model 2 – Falsification
Model 3 – Paradigm shifts

These are linked to the ideas of Bacon, Popper and Kuhn.

The vignettes provided (and teachers may wish to substitute or supplement these examples) are of the work of: Marie Curie; Albert Einstein; William Harvey; Robert Millikan; Barbara McClintock; Crick, Franklin, Wilkins & Watson; Galileo Galilei; Lise Meitner; Jane Goodall; Johann Kepler

As with most of the ASCEND activities, the tasks are designed to encourage active discussion, rather than being focused on specified end points. The different vignettes do not collectively suggest any one of the models is adequate – and this reflects the lively debate among those who study such matters!

ACTIVITY 3: LEARNING SCIENCE

This activity asks students to identify and summarise key information from the 'learning sciences', and to produce a model synthesising the information.

In this activity, students work in groups to engage with information about the brain and about learning, and produce two outcomes: a model of the learner and a set of 'tips for learners' that they could use as advice on study/revision skills for other students. The two tasks require the groups to organise and present information from the same 'database' in two very different ways.

The 'The Brain and Learning' text is designed to introduce a wide range of ideas related to learning, from both the psychological and the more physiological perspectives.

The text is deliberately designed to be 'dense' introducing a wide range of ideas, and new vocabulary for students to use. The text relates familiar science ideas (the brain, blood, cells), familiar everyday ideas (imagining, remembering), and (what are likely to be) new concepts and vocabulary (glial cells, cerebrospinal fluid). The text is designed to be a demanding yet interesting read for students. They need to have the ability to 'read for purpose' – to identify texts, skim them, determine whether they are relevant to matters in hand, and then select the parts of a text from which they will obtain information. Gifted learners (in particular) are likely to take more responsibility for finding a suitable source and interrogating it when they need information.

ACTIVITY 4: EXPLAINING SCIENCE

This activity explores the nature of a good scientific explanation.

The aim of the session is to help students

a) appreciate that explanation play a central role in science

b) to have criteria for 'good scientific explanations': in science explanations are expected to:

i. be logical;

ii. be based on evidence and/or accepted scientific ideas;

iii. usually be consistent with accepted scientific knowledge

The session includes two activities. The first involves students working in pairs forming their own explanations for phenomena, and then swapping their explanations with another pair. The second activity involves evaluating a mooted set of explanations.

The first activity is designed to get students discussing possible explanations, and so provide a starting point for thinking about what a good explanation might be in the context of specific target phenomena.

The second activity involves the students, working in groups, considering a set of prepared explanations (many designed with specific flaws – some more subtle than others) and selecting examples of good and poor scientific explanations. For this activity, the students are provided with some suggestions about what makes a good or poor scientific explanation. Teachers may decide to allow students access to this support material only after they have spent some time working on the exercises based on their own ideas.

ACTIVITY 5:
IDENTIFYING PATTERNS IN SCIENCE

This activity asks students to undertake three simple practicals, and collect data from which they can identify 'laws.' Students are supported to develop an explanation of the general pattern of exponential decay in terms of a negative feedback cycle.

This session is laboratory-based, where students are asked to identify patterns (laws) in three different physical contexts: cooling, water flow, capacitor discharge. A key purpose of the session is to introduce another important 'nature of science' (see Chapter 4) idea, that of the 'law'. The three activities have been selected because they offer the potential for recognising similar patterns (i.e. the exponential decay curve), and for linking with some abstract theory (about feedback cycles) that could offer an explanation of the patterns. The activities are set-up using the well-known POE – predict, observe, explain – approach, where students are encouraged to engage with understanding a phenomenon by initially making a prediction, which they then test against observations. The three practical activities are:

- Identifying patterns – cooling: "Everyone knows that 'hot objects cool down', but does this always happen?"
- Identifying patterns – water flowing downhill: "We all know that water flows downhill – but what determines how quickly water runs downhill?"
- Identifying patterns – capacitor discharge: "make a prediction: do you think the current will have a steady value during discharge?"

Two types of support material are provided for students. Information is provided on *laws* in science (complementing the sheet provided during the explanations activity), to be distributed near the start of the session, and some material introducing 'systems' is provided which relates to the particular common type of pattern being explored in the three experiments (i.e. exponential decay). Teachers should use their judgement in deciding when to introduce this, and 'differentiation by support' (see Chapter 3) may be appropriate.

ACTIVITY 6: SCAFFOLDING INDIVIDUAL LEARNING IN SCIENCE

This activity is a computer-based learning activity using level 3 (i.e. A level) physics materials designed for student self-study.

The computer-based learning (CBL) activity is an opportunity to work with some materials developed for independent learning of physics in the post-16 sector (see Chapter 6). It also allows students to work independently, although they are allowed to work together if preferred. Students are given the choice of working through a range of topics from the National Learning Network (NLN) Level 3 Physics CBL materials.

This activity is provided to give students a taste of Physics at A level. Physics is a highly abstract subject, involving a good deal of mathematical formalism (albeit largely limited to algebra at A level). These are features that readily deter many students, but can be attractive for more highly-attaining students.

In the ASCEND project students were advised to select from the NLN level 3 introductory units:

- **electricity** – conductivity and resistivity
- **fields and forces** – the gravitational field strength at different distances from the Earth's surface
- **quantum phenomena** – demonstration of the photoelectric effect
- **radioactivity** – properties of alpha, beta and gamma radiation
- **waves** – diffraction of water waves and light waves

Each of these units was considered to offer a taster of physics study post-GCSE which would be accessible for more able students.

ACTIVITY 7: INTEGRATED SCIENCE?

This activity is designed to allow students to appreciate how ideas from different science disciplines can be synthesised, specifically in the context of a model of plant nutrition.

In this activity, teams of students work as project teams, and are assigned roles as project manager, biologist, chemist and physicist. The team has to produce a poster to explain ***how a plant manages to obtain the energy and materials needed to live***.

The activity is set up so that the science specialists are each briefed with some of the information that is needed to provide a good overview of plant nutrition (at a suitable level of sophistication for students studying at GCSE level), and a sense that a good overall 'picture' can be developed by considering how the specialist knowledge of the biologist, chemist and physicist may be related. This approach reflects a view that students readily compartmentalise their knowledge. Yet finding the links between topics (and so developing the overall picture) is both essential to appreciating the nature of science (which develops a largely coherent, and mutually supporting knowledge network) and, also, the type of activity that we expect to both challenge and motivate the most able.

The project manager's brief provides criteria for a 'good' poster – that it will explain:

- why roots often spread out into the soil
- why leaves are green
- why leaves have spongy tissue
- why leaves have pores
- why the stomata are usually only on the underside of the leaves
- why leaves are often supported on stems, and spread out in different directions
- why some plants have underground stores of starch.

The students are also asked to ensure the poster provides information at a cellular level: that the "poster should make it clear how *individual cells* throughout the plant get their supply of carbon, nitrogen and energy".

ACTIVITY 8: SCIENCE IN SOCIETY

This activity asks students to respond to common public objections to the high level of scientific confidence in the theory of evolution by natural selection

Activity 7 was set in the context of scientists needing to communicate about their work to the public. Activity 8 develops this link ("It is the responsibility of scientists to explain our work to the public who ultimately fund our research"), and concerns public unease with 'gene technology', and more extreme views about the status of evolution (i.e. by natural selection) as a scientific theory. Students, working in groups, are asked to suggest how to respond to a letter from a pressure group which denies that life on earth could have evolved. This scenario is based on common objections that are raised, and which may appeal to 'common sense':

- something like a green plant, with all its complex structure, could not possibly come about by chance
- there is so much variety in living things that they cannot possibly be derived from common ancestors
- left to their own devices, living things are not going to breed to 'improve' the species
- no one has ever managed to breed sheep from dogs, no matter how much they have selected the parents
- parents always leave offspring of the same type
- if man had evolved from monkeys, then why are there still monkeys?
- why do the genes for some diseases seem to get passed on so effectively?

Responding to these objections with sound arguments requires a good understanding of the theory of evolution by natural selection!

As with the previous activity, this is set in the context of the public understanding of science. Also, as with the Activity 7, the topic (natural selection) has been chosen because experience suggests that even able students may fail to see the 'whole picture' and take away from school science a partial understanding of the key arguments used to support evolutionary theory. As the students are told in the briefing information: "the reasons so many people doubt evolution are that (a) it has occurred over such a long time scale, and (b) evolution only makes sense when someone understands how a number of separate key ideas fit together". Activity 8 develops ideas from previous ASCEND activities on the need to integrate different ideas (Activity 7), and the nature of a scientific explanation (Activity 4), as well as – like most of the ASCEND activities - involving teamwork and a form of modelling activity.

ACTIVITY 9: JUDGING MODELS IN SCIENCE

This activity asks students to evaluate the usefulness of competing / complementary models in two different contexts by examining whether the models can explain data.

This activity comprises of two related tasks. In both cases, the task concerns comparing two 'competing' models:

Task	'Competing' models of:	Judged against:
Choosing between models (1)	Particle theory (Model 1 vs Model 2)	Application to explaining common phenomena
Choosing between models (2)	Ionic bonding (Model A vs Model B)	Application to explaining properties of NaCl

In each case students, working in groups, consider the merits of alternative models in providing explanations. The second task can include some simple practical work, making observations. The groups are provided with sets of cards with features of the models, and the phenomena/properties to be explained, to sort during the tasks.

This activity reinforces the central role of modelling in science, and the way that models are used in science to support explanations. In the two tasks students are asked to consider the merits of alternative models in explaining data. The tasks have been designed to generate discussion, and it is not intended that students will be able to simply select a 'better' model that fits all the data. This is especially the case in Task 1, 'Using the particle model', where neither model is suitable for explaining *all* those phenomena that scientists use particles ideas to explain - and in school science different versions of particle theory are used at different stages, and in different topics. Part of the rationale of this activity is to help students appreciate that models are used in this way, and that often nature is too sophisticated to be represented by a single simple model.

Task 2 is slightly different in that the two models being compared are not of similar status in terms of school science. Model B reflects a level of scientific understanding that is suitable for explaining properties of NaCl at a level appropriate for students of this age group. Model A is based on the type of thinking about ionic bonding that commonly develops in students by age 16 but which has limited value in explaining the properties of NaCl. Despite its clear inferiority, this type of model has been found to be readily adopted by students, perhaps even being intuitively attractive. [118]

Therefore, although the evidence *should* offer a clear preference for model B as having more value, it is likely that many students will initially find model A attractive.

ACTIVITY 10:
LINKING SCIENCE TO THE EVERYDAY WORLD

In this activity students are invited to use their imagination and understanding of science topics to create novel analogies for scientific concepts

'The analogy game' is a card game based upon finding analogies between scientific concepts and everyday activities. The game is suitable for groups of students, possibly group sizes of 5-6 (or even larger) depending upon the group dynamics. Students are 'dealt' blue 'concept cards' and green 'analog' cards, and must use their concept cards to form analogies that the other players find convincing. The first player to have successfully formed analogies for all their concept cards wins.

'The analogy game' was used in ASCEND as a 'fun' activity. However, it was designed with serious purposes. One of these involved introducing the notion of analogy as a tool used in science. Scientists use analogies a good deal to make sense of phenomena – either making analogies with existing scientific ideas, or (as in the game) with more everyday phenomena. Although analogies of this type do not assure an understanding of new areas of science, they have certainly provided scientists with fertile starting points for exploring new explanations and understandings. Analogies provide familiar models to test, critique, extend or dismiss.

A parallel purpose of the game is to provide an opportunity for students to demonstrate their creativity. The most gifted science learners may be those who are able to make connections and see links that others do not notice: the analogy game provides an outlet for divergent, creative thinking, making the task even more open–ended.

The default rules set out such parameters as how many cards of each type are dealt to each player, and when and how cards may be swapped. It is suggested that any attempts by players to improve the running of the game by modifying the rules should be encouraged, as long as such changes are made by consensus within the playing group.

CHAPTER 8:
RESPONSES TO THE PROGRAMME

The ASCEND programme ran over seven sessions, approximately fortnightly. Student enthusiasm for the programme was clear, although there is no doubt that some of this was linked to the social aspects (meeting same-sex and opposite sex peers from other schools), and perhaps the novelty and prestige of working in the University environment. The numbers attending each session were mostly in the 20-30 range. Some students were very regular in their attendance, and others less so, but the general impression was that they certainly appreciated the opportunity to be involved.

Student comments about the programme

Students attending the final meeting completed a questionnaire at the end of the session, that included several open questions (see Box 3), and copies were sent out to the schools for other students who had attended some of the previous sessions. We were interested in finding out which aspects of the programme students found especially enjoyable, interesting and challenging, as well as how they considered the sessions differed from school science lessons. They were also asked what they thought helped them learn science, and what changes they might suggest to the ASCEND approach:-

- What did you enjoy most about being involved in this project?
- What did you find most interesting about the activities?
- What (if anything) did you find most challenging about the sessions?
- How were these sessions different to the science lessons you have at school?
- What type of activity do you think helps you learn science?
- Were there things you did not enjoy / would change?

Enjoying science

In terms of enjoyment, three particular themes can be identified in the feedback. The students enjoyed the way most of the activities were based around group work, e.g. "working in groups to work out things", and some of this related to being in a group from several schools, i.e. the "chance to work with different people". Recognising that the topics went beyond the school curriculum was also appreciated, i.e. "getting the opportunity to do things we don't do at school" or even "learning stuff that cannot [sic!] be learnt in school". In particular, there were a number of comments suggesting the activities had tapped into ways of thinking that were not commonly used in school science. So one student enjoyed "exploring new ideas and a new way of thinking [as] we were not just told facts but asked to think and question our knowledge". The notion of novelty was also reflected in "thinking about more complex things that I haven't thought about before".

The way the activities were set up was appreciated, as much as the topics met. Students enjoyed "getting the opportunity to tackle interesting and stimulating problems"; "learning things using different approaches to the ones we use at school"; and "being involved in interesting discussions". One student explained:

> **"It stimulated me to think about science from different angles. Made me think about simple things on a deeper level than I've been taught. Made me realise how little of the simple things I remember".**

Interesting science activities
Again, students were interested in "learning things we would not learn at school". A number of the students, explicitly linked interest with being encouraged to think:

- "Expanding my train of thought"
- "Working things out from first principles"
- "Seeing connections between things and learning new points"
- "The independence and depth of thinking required"

Debate and discussion were considered to make the work interesting, for example: "Discussions about our opinions. Hearing others' views. Brainstorming." One student noted how finding out existing ideas were incorrect made work interesting: "bettering my scientific understanding, especially after being told I was wrong".

Challenging science activities
Interestingly students recognised that some of the features that made the sessions enjoyable and interesting were those that made the work challenging. Challenge came from:

- "Trying to specify one answer and cutting down many good answers to one real answer"
- "Reasoning my ideas, not just taking what I had been taught on face value"
- "Thinking about the connections between various things"
- "Thinking for myself, thinking beyond the box"
- "Wrapping my head around new ideas and new points of view"

One of the students explained that the work was challenging because of:

> **"In-depth discussions - really made you think. YOU thinking for yourself, not being told answers, having to get these yourself".**

Comparison with school fare

The students had explicitly mentioned how the programme differed from usual school activities in their answers to previous questions. In response to being specifically asked about the differences, they referred to the sessions offering "more independent thinking", "less influence from teachers, more independent discussion".

One student referred to how "they [sic] made us do the work rather than being told it", and another reported "having to come to our own answers and conclusions, making you think". The approach was described as "less answers and more questions" and one of the delegates summarised the difference thus: "We were given a lot more space to think for ourselves and allowed to develop ideas further".

Overview of the programme

Most of the feedback was very positive. Practical work was considered useful in learning science by quite a few of the students, and some would have liked more 'practicals' in the sessions. Despite the comments about independence, some students would have liked more guidance. At least one student thought there were too many activities based around cards (a useful way of feeding-in information to be considered or sorted whilst avoiding too much direct teacher input). There were surprisingly few references to the large number of adults present (so that typically each group of four students had a member of the research team in close proximity at all times). Where this was commented upon, it was interpreted variously: being described both as

> **"having strange people taking notes and recording us"**

and

> **"getting the opportunity to work with a group of experienced scientists".**

I will leave the last word on the student experience to one of the delegates. Shortly after the programme ended, one of the partner schools included this account in a newsletter home to parents:

> **"Over the last few months, a group of researchers from [the University] have been conducting fortnightly sessions on various science topics, to see how we, as Year 10 students, reacted to them. These sessions were a lot of fun, for a variety of reasons. It was an interesting opportunity to mix with our peers from various other schools in the area, and the topics were very mind broadening, because we were largely left to our own devices, having been given some points and ideas to discuss. This meant we could have lengthy discussions with people from both our own and other schools who are as interested in science as we are, and we had lots of helpful science graduates around to help us, both by giving extra data and by making us consolidate our ideas by questioning us on precisely what we meant. The sessions were, if anything, too short, as they had provided lots of materials to analyse and discuss for each session. I think that the type of free discussion that was engendered was very helpful to us, but only because it was guided closely. Each session had a goal in mind, and this provided a focus for the discussions, which might otherwise have faltered more easily. If any opportunities arise for this type of thing again, I heartily recommend it to anyone who is interested in science."**

EPILOGUE

All of the activities described here have been used in the ASCEND project with 14-15 year olds, and all were found to challenge and stimulate students. We found that the extent to which students and groups were happy to work with limited direction (as in many of the ASCEND activities) varied. Some gifted students relished the opportunity: other students at the sessions sought more prescriptive instructions. We suspected that this was in part related to students not being used to being offered that level of responsibility in school science. These students generally experienced school science as having highly specified outcomes, and clearly mandated means of reaching those outcomes [111]. Being allowed to decide how best to meet goals, and how to go about organising themselves in the pursuit of the set goals was generally not a common experience. This is not a criticism of school science, as the constraints of classroom teaching and the National Curriculum are well known. Initially, we had to adjust our approach to offer more support to some groups than we had intended. However, on the whole the students at ASCEND, once convinced they really could decide how to go about the tasks, welcomed the opportunity to take charge. We suspect that given regular experience of working this way, these learners were mostly capable of being highly cooperative in group-work, and are able to plan and evaluate their own work with much less external support than is usual in a school science context. Working in this way can help developed important 'life-skills' as well as making science more challenging and engaging. We would recommend withdrawing and delaying support as long as students are engaged in exploring ideas and not getting frustrated.

Although all the activities were tested during ASCEND, we have not had the opportunity to engage in thorough evaluation in a variety of contexts. No doubt some activities are not optimally designed – and may be improved by adapting to local needs and circumstances. Teachers are invited to use the materials as they are, to select from them, modify them, or simply to design their own activities informed by the spirit of the ASCEND activities. If the materials help teachers challenge the most able science learners – either through direct use, or by inspiring other ideas – then the ASCEND project will have been a success.

FURTHER READING:

The following two documents, although written from a USA perspective, offer useful advice, and are freely available by download from the web:

- Nebraska Department of Education (1997) *Promising Curriculum and Instructional Practices for High-Ability Learners Manual*, http://www.nde.state.ne.us/Hal/Promising.htm http://www.nde.state.ne.us/HAL/PromisCURR.pdf (accessed 6th August 2006)
- Stepanek, Jennifer (1999) *Meeting the Needs of Gifted Students: Differentiating Mathematics and Science Instruction*, Portland, Oregon: Northwest Regional Educational Laboratory. http://www.nwrel.org/msec/resources/justgood.html (accessed: 6th August, 2006)

The APECS (Able Pupils Experiencing Challenging Science) project: information about the Cambridge Seminar Series (2002-5), and material from some of the seminars may be found at http://www.educ.cam.ac.uk/apecs/index.html (accessed 6th August, 2006). The seminar series forms the basis for many of the contributions in a new book – *Science Education for Gifted Learners* – from Routledge, which is expected to appear in 2007.

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